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**Published**
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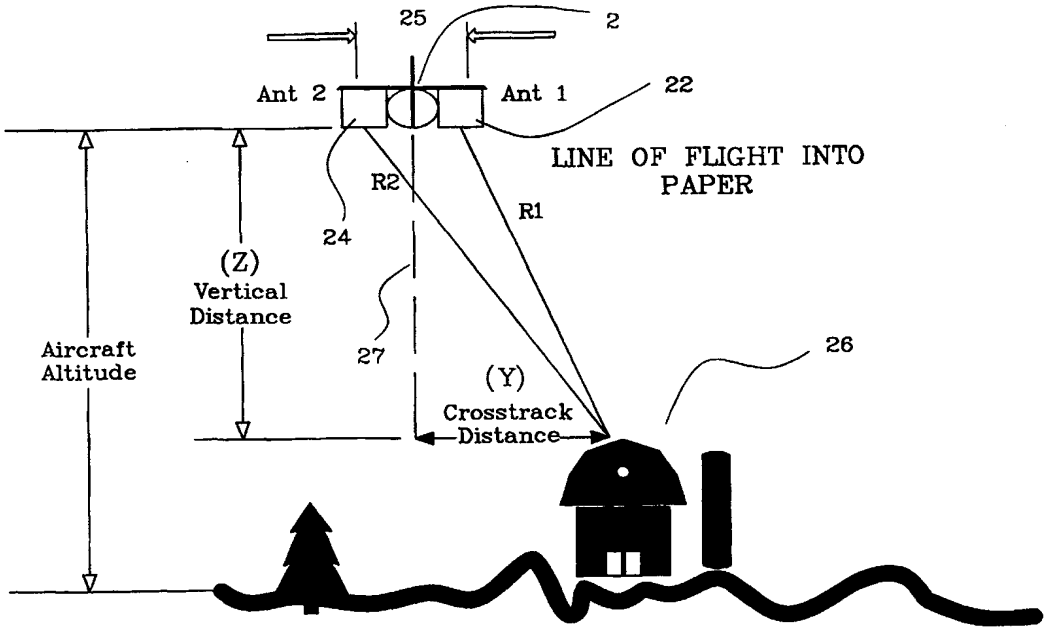
**(54) Title:** INTERFEROMETRIC SYNTHETIC APERTURE RADAR ALTIMETER




**(57) Abstract**

Aircraft position determination system includes a transmitter to transmit a signal (10), and two receivers (22, 24) to receive the transmitted signal reflected from the terrain below the aircraft, and a phase comparison apparatus (96) operating from the two receiver's inputs. A processor determines position based on the output from the phase comparison apparatus.

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# INTERFEROMETRIC SYNTHETIC APERTURE RADAR ALTIMETER

## BACKGROUND OF THE INVENTION

The proper navigation of an aircraft in all phases of its flight is based to a large extent upon the ability to determine the terrain and position over which an aircraft is passing. In this regard, instrumentation, such as radar systems, and altimeters in combination with the use of accurate electronic terrain maps, which provide the height of objects on a map, aid in the flight path of the aircraft. Electronic terrain maps are well known in this area of technology and no further discussion in the creation of electronic terrain maps will discussed. Presently, electronic terrain maps are used to assist in the navigation of aircraft.

Fig. 1 shows an aircraft 2 with the Doppler effect illustrated by isodops as a result of selection by the use of Doppler filters. The area between the isodops of the Doppler configuration will be referred to as swaths. The Doppler filter, and resulting isodops are well known in this area of technology and will not be explained in any further detail. Further, the aircraft 2 in the specification will be assumed to have a vertical velocity of zero. As is known, if a vertical velocity exists, the median 8 of the Doppler effect will shift depending on the vertical velocity. If the aircraft 2 has a vertical velocity in a downward direction, the median of the Doppler would shift to the right of the figure. If the aircraft 2 has a vertical velocity in an upward direction, the Doppler would shift to the left of the figure. Again, it will be assumed in the entirety of the specification that the vertical velocity is zero for the ease of description. However, it is known that a vertical velocity almost always exists.

Radar illuminates a ground patch bounded by the antenna beam 10 from an aircraft 2. Fig. 1a shows a top view of the beam 10 along with the Doppler effect and Fig. 1b shows the transmission of the beam 10 from a side view. To scan a particular area, range gates are used to further partition the swath created by the Doppler filter. To scan a certain Doppler swath, many radar range gates operate in parallel. With the range to each partitioned area determined, a record is generated representing the contour of the terrain below the flight path. The electronic maps are used with the contour recording to determine the aircraft's position on the electronic map. This system is extremely complex with all the components involved as well as the number of multiple range gate that are required to cover a terrain area. As a result, the computations required for this system are very extensive.

In addition to the complexity, the precision and accuracy of the distance to a particular ground area or object has never been attained. As is well known in this area, a larger antenna would result in a greater accuracy. For satellites and larger vehicles, a larger antenna could be used and precise, accurate determination of position could be performed. However, for aircraft and other smaller flying apparatus such as missiles for example, it would be infeasible to use a large antenna. It would be desirable and beneficial if a smaller, precise navigational means could be used. Furthermore, it would be desirable and beneficial if a less complex system for determining the position of an aircraft existed.

## SUMMARY OF THE INVENTION

An aircraft position determination system includes a transmitter and two receiver channels. The transmitter transmits a signal, and a first receiver channel with its Doppler filter selects the next swath ahead for range determination of the highest object and at the same time, a second receiver channel with its Doppler filter selects the swath directly below the aircraft for exact positioning of the highest object. During the last portion of the present invention's operation time interval, both channels select the swath directly below the aircraft and set a range gate to the exact range position of the highest object and a phase comparison of the signal return made between the two channels is performed. This information is used to determine the aircraft position.

## BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1a shows a top view of the aircraft illustrating isodops corresponding to the Doppler filter bounds as well as a beam area transmitted by a transmit antenna on the aircraft.

Fig. 1b shows a side view of the aircraft and the beam transmitted from the transmit antenna from the aircraft to the ground.

Fig. 2 shows a timing sequence of the operation for the present invention.

Fig. 3 shows a view of an aircraft going into the figure with two receive antennas receiving reflected signals off an object originally transmitted by the transmit antenna.

Fig. 4 shows a block diagram of the present invention.

Fig. 5 shows a more detailed implementation of the present invention.

## DETAILED DESCRIPTION OF THE PRESENT INVENTION

The present invention provides a smaller, more accurate navigation means than existing navigation means. The present invention uses topographic/elevation mapping as described in the background of the invention along with the present invention for precision navigation. Not only is the present invention more precise and smaller, but also less complex. As a result of fewer components, the present invention will be far less expensive as well. The present invention functions as a combination Doppler radar/interferometer to navigate an aircraft 2 with respect to terrain features below the aircraft 2. The present invention also functions with the use of an electronic map, as described in the background of the invention, in determining the position of the aircraft 2. In addition to determining the altitude of the aircraft 2, the height of the highest object above the ground and the XYZ location of the highest object with respect to the aircraft 2 in a certain terrain area can be determined.

As an aircraft 2 is flying over terrain as shown in Figs. 1a ,1b, and 3 it is important to determine the position of the aircraft 2 in accordance with a map. The present invention uses a Doppler filter and range gate with a transmitted beam 10 from a transmit antenna. Two receive antennas, Antenna 1 22 and Antenna 2 24, are used in the present invention to receive information. Along with the two antennas, two channels, Channel 1 and Channel 2 for Antenna 1 22 and Antenna 2 24 respectively, are used to perform operations in determining the position of the aircraft 2. Each channel includes an antenna, gate, Doppler filter and a tracker.

The first antenna, Antenna 1 22 of Channel 1, along with a high speed tracker 97a will provide a course range search which roughly determines the range to the highest point 26 in the swath 12 before the swath 14 the aircraft 2 is currently over. Determination of the highest point 26 is performed by a wide bandwidth, hi speed track loop (provided by the tracker 97a) which quickly determines the range to the highest object 26 in the swath area 12 thus providing a starting point for Channel 2's track loop. Track loops are well known in this area of technology and control the range gate to track returns from the transmit antenna. A narrow bandwidth, high precision tracker 97b is used to set Channel 2's range gate 36 to the exact range of the highest point 26 based on Channel 1's previous course range determination since it is always one swath ahead of Channel 2. The operation of the two receive antennas and associated channels provides a quick and accurate setting of a range gate on the nearest object in the Doppler swath 14 directly below the aircraft 2 so that a phase difference can be measured and along

with the known separation 25 between the two antennas, the crosstrack distance to the object 26 is determined. The crosstrack distance is the distance from the ground directly below the aircraft 2 to the object 26. Crosstracks are well known in this area of technology. Further, radar range trackers are well known in this area of technology and a description of their operation will not be discussed here.

Fig. 2 shows the timing of the operation of the present invention which is crucial to the invention. Antenna 1 22 and a high speed track loop determine the range to the highest point in swath 12 selected by the Channel 1 Doppler filter 94a. Channel 2, at the same time that Channel 1 is receiving information from swath 12, receives information on range of the highest point 26 in swath 14. The information received by Channel 1of swath 12 is saved in memory for the next time period. Once Channel 2 has received the course range from Channel 1 (determined in the previous time interval) and accurately sets its range gate to the range to the object 26, the rest of the period is spent in comparing the phase difference between R1 and R2 of swath 14 where R1 and R2 are the current distances from the respective antennas, Antenna 1 22 and Antenna 2 24 to the highest object 26. As can be seen, approximately half the period is spent accurately setting the gates to the highest object in a swath and the other half of the time period is spent comparing the phase difference.

Fig. 3 shows a view with the aircraft 2 coming out of the figure. As stated previously, during the phase comparison portion of the time interval, the Doppler filters of both Channel 1 and Channel 2 are set to select the swath 14 directly below the aircraft 2 and further, both range gates are set at a range directly on the highest object 26 as determined during the first portion of the time interval by Channel 2. For example, during the first interval, Channel 1 will determine the range of the highest object 26 in swath 12 to be approximately 4,050 feet away. This is stored in memory so when the first interval of the next time interval occurs, Channel 2 will set the range gate at 4,050 feet in swath 14, which was the swath ahead in the previous time interval, and more accurately determine the range. Since Channel 2 uses a more accurate tracker 94b, it may determine that the actual range of the aircraft 2 to the highest object 26 is 4,000 feet. Then, in the second interval of the time interval, the range gates of both channels are set to a range of 4,000 feet. From this range, Antenna 1 22 receives a signal from the object 26 at a distance of R1 and Antenna 2 24 receives the signal from the same object 26 at a distance of R2 where the distance difference is a function of the antenna separation 25. A phase comparitor 96 compares the phase difference between R1 and

R2 once the return signals are received. Phase comparitors are well known in this area of technology and its operation will not be discussed in any further detail here. As Fig. 3 illustrates, R2 is calculated directly from the phase difference and simple trigonometry relations are used to determine the exact crosstrack distance to the object 26.

As Fig. 3 illustrates, after the phase difference is determined, R2 can be calculated knowing R1, antenna separation 25, and phase difference. Crosstrack distance (Y) and vertical distance (Z) can also be computed. When the crosstrack distance computes to 0 feet continuously for many Doppler swaths and without abrupt range changes, then the system is tracking the ground directly below the aircraft 2 and further, there are no objects of significant height in its path. An algorithm can obviously be provided then to determine aircraft altitude from the normal operation of this system. The height of the object with respect to surrounding terrain can then be computed by subtracting the vertical distance to the object from the aircraft altitude. Further, the processor also determines the aircraft's position according to the electronic map.

Fig. 4 shows a block diagram of an embodiment of the system of the present invention. A transmitter 32 transmits the beam 10 signal. A first receiver 22 receives a return signal in swath 12. A second receiver 24 receives a return signal in swath 14. After passing through gate/correlators and IF strips, the received information is converted to digital data to be processed. A Doppler filter 44 and 46 passes only information from the desired swath and the range gate and tracker are used to develop a track loop to pass information only from the range corresponding to the highest object 26. A phase comparitor 96 performs the a phase comparison of the return signal of the highest object 26 and a processor 98 uses this information to determine the altitude and position. After the position is determined, a map match processor correlates the information and determines the aircraft's location according to the map. Therefore, if the aircraft 2 is not on course to its destination according to the map, correction can be provided to maintain the correct course.

Fig. 5 provides a more detailed view of the present invention. The transmitter 32 sends the signal to the terrain. The transmitter configuration is well known in this area of technology and will not be discussed further. The first and second receivers 22 and 24 have similar configurations and the first receiver will be described in which the description is applicable to the second receiver as well. The receiver 22 receives the signal reflected back from the terrain. A preamplifier 70 amplifies the signal. A mixer 74 converts the signal to a first intermediate frequency (IF) where the signal is then

amplified again by a first amplifier 78. The signal is then sent to a gate 36 which performs the range gate operations described earlier in this detailed description. The signal is then sent to a second IF strip 42. The IF strip 42 has a mixer 82 to convert the signal to a second intermediate frequency. The signal is amplified by a second amplifier 86 and sent to a narrow band filter 90 which performs pulse to pulse integration. The signal is then sent to an I/Q mixer 46 which converts the return to baseband frequency and provides in-phase and quadrature phase outputs to the digitizer for positive and negative Doppler frequency determination which indicates the direction of the aircraft 2. I/Q mixers are well known in this area of technology and a more detailed description of its operation will not be discussed. Once the return from the I/Q mixer 46 is digitized by a digitizer 46, the Doppler filter 94 of the processor 48 is set to pass only the desired Doppler swath as determined from the vertical velocity provided by the vehicle's internal navigation system. As stated previously, the vertical velocity has been assumed to be zero for the ease of description. However, the vertical velocity is rarely zero and the value of the vertical velocity would be utilized at this point of the present invention in determining the desired swath. The phase comparitor 96 then determines the phase difference between the range received from the return signals of the two receivers and the position processor 98 determines the altitude of the aircraft 2, the height of the highest object and the crosstrack location of the object from the path of the aircraft 2.

It should be recognized that many components in the present invention can be interchanged with other components with similar operations. Further, the present invention may incorporate addition or deletion of some components as long as the spirit of the invention is maintained. The present invention is not limited to the embodiment as shown in Figs. 5 and 6, but rather Figs. 5 and 6 are shown as examples of the present invention.

The invention has been described herein in detail in order to comply with the Patent Statutes and to provide those skilled in the art with the information needed to apply the novel principles and to construct and use such specialized components as are required. However, it is to be understood that the invention can be carried out by specifically different components, and that various modifications can be accomplished without departing from the scope of the invention itself.

## CLAIMS

1. System for determining the position of an aircraft, comprising:

transmitter transmitting a signal to terrain below the aircraft;

first receiver receiving the signal reflected back to the aircraft upon contact with terrain in a first area wherein the first area is terrain ahead of the aircraft;

second receiver receiving the signal reflected back to the aircraft upon contact with terrain in a second area wherein the second area is the terrain the aircraft is currently over wherein the first and second receivers are separated by a separation distance; and

apparatus for determining position of the aircraft based on information received from the signal reflected back to the aircraft.

2. The system of claim 1wherein the apparatus for determining first determines an approximate range to a highest point in the first area and an accurate range to a highest point in the second area.

3 The system of claim 2 wherein the approximate range is stored in a memory.

4. The system of claim 3 wherein the accurate range is determined by using the approximate range stored in memory to perform a range analysis to determine the accurate range.

5. The system of claim 4 wherein the first receiver and the second receiver receive a signal transmitted, by the transmitter, to the highest point in the second area to determine a first range and a second range and calculate the position of the aircraft to the highest point based on the difference between the first range and the second range, and the separation distance.

6. The system of claim 1 wherein the determining apparatus determines the altitude of the aircraft from the information received from the signal reflected back to the aircraft.

7. The system of claim 1wherein the apparatus for determining compares the position of the aircraft, in regards to the highest points, to a map and determines a map position of the aircraft.

8. The system of claim 1 wherein both receivers further comprise:

an antenna;

a range gate;

a Doppler filter; and

a tracker.

9. The system of claim 1 wherein the apparatus for determining further comprises:
a phase comparitor; and
a position processor.

10. System for determining the position of an aircraft, comprising:
transmitter transmitting a signal to terrain below the aircraft;
receiver determining a highest point in the terrain below and receiving a plurality of signals reflected back to the aircraft from the highest point; and
an apparatus comparing information received from the signals reflected back to the aircraft and processing the information to determine the position of the aircraft.

11. The system of claim 10 wherein the comparing apparatus determines the altitude of the aircraft from the information received from the signal reflected back to the aircraft.

12. The system of claim 10 wherein the apparatus for determining compares the position of the aircraft, in regards to the highest points, to a map and determines a map position of the aircraft.

13. The system of claim 10 wherein the apparatus for comparing further comprises:
a phase comparitor; and
a position processor.

14. The system of claim 10 wherein the receiver further comprises:
a first antenna;
a second antenna;
a range gate;
a Doppler filter; and
a tracker.

15. The system of claim 14 wherein the signals received represent a first range received by the first antenna and a second range received by the second antenna and the comparing apparatus calculates the position of the aircraft to the highest point based on the difference between the first range and the second range and distance between the first antenna and the second antenna.

16. Method of determining the position of an aircraft, comprising the steps of:
transmitting a signal to terrain below the aircraft;
receiving the signal reflected back to the aircraft upon contact with the terrain in a first area wherein the first area is terrain ahead of the aircraft;

receiving the signal reflected back to the aircraft upon contact with the terrain in a second area wherein the second area is the terrain the aircraft is currently over;

determining a highest point in the second area;

determining a first range and a second range of the aircraft to the highest point in the second area; and

comparing the first range and second range to determine the position of the aircraft from the highest point based on difference between the first range and the second range.

17. The method of claim 16, further comprising the steps of:

determining altitude of the aircraft based on the position of the aircraft, first range, and the second range.

18. The method of claim 16, further comprising:

comparing the position of the aircraft, in regards to the first area and the second area, to a map and determining a map position of the aircraft.

*Fig. 1a*

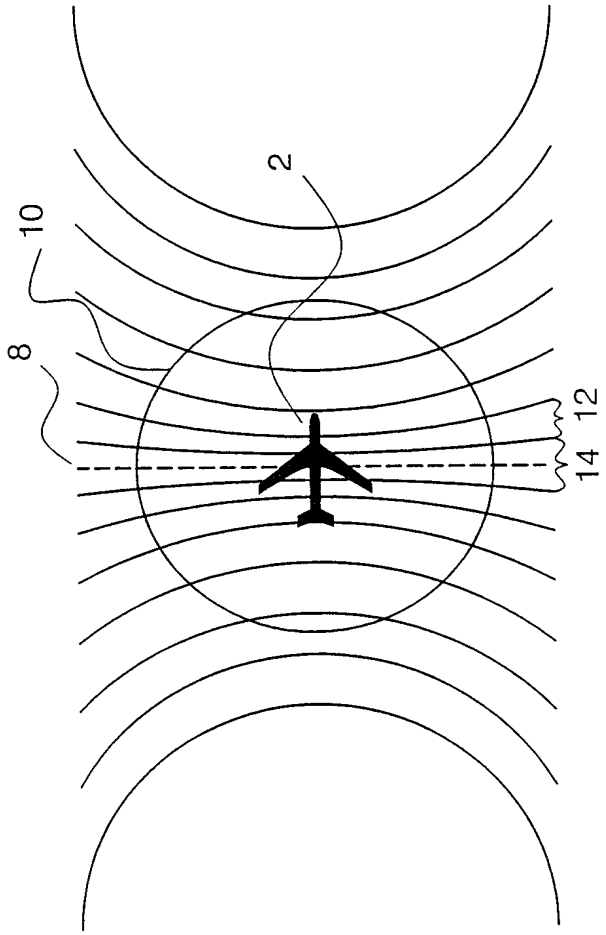
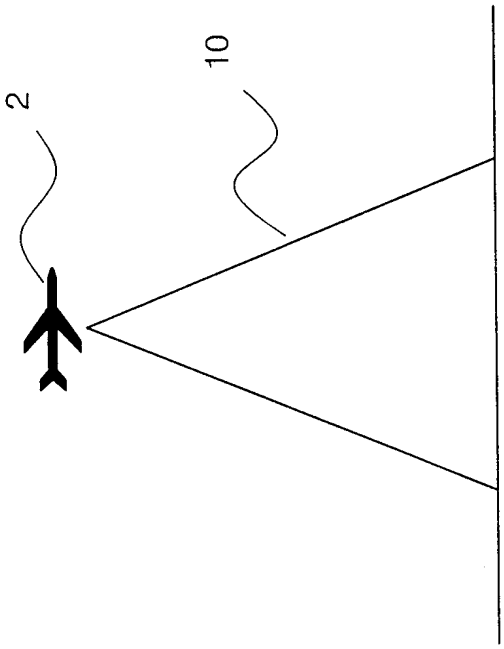



*Fig. 1b*



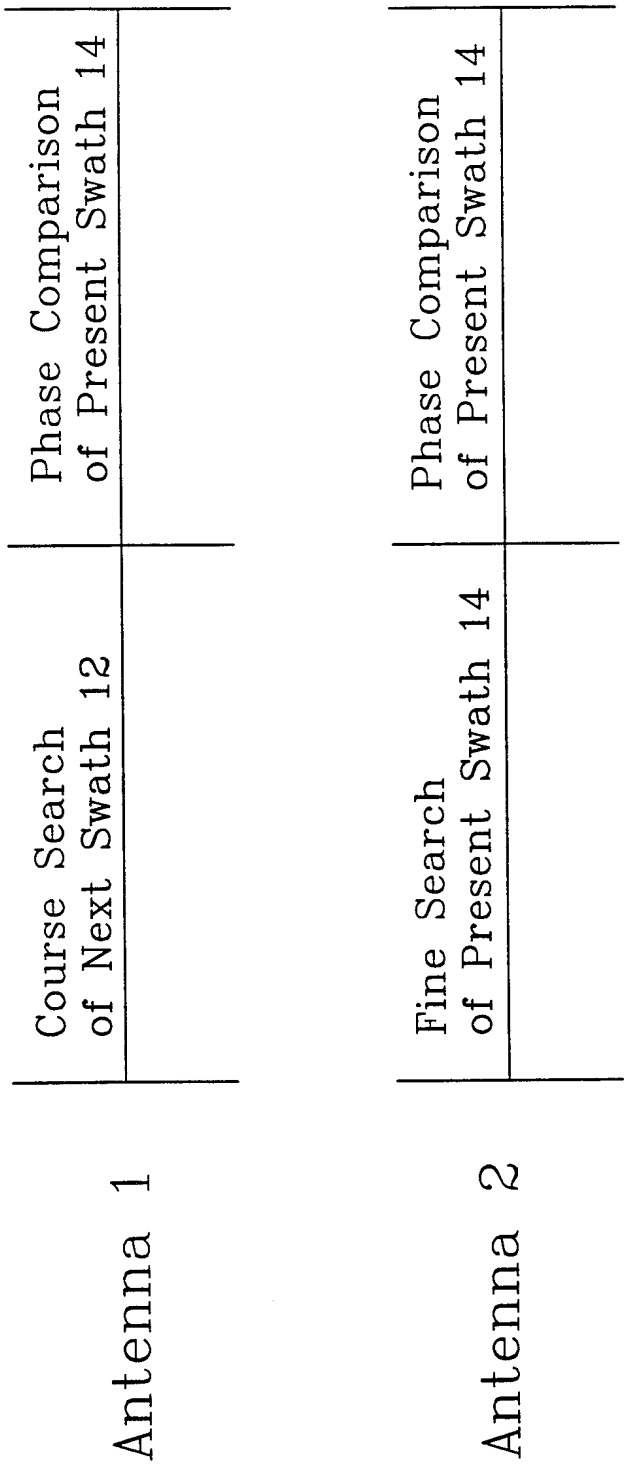
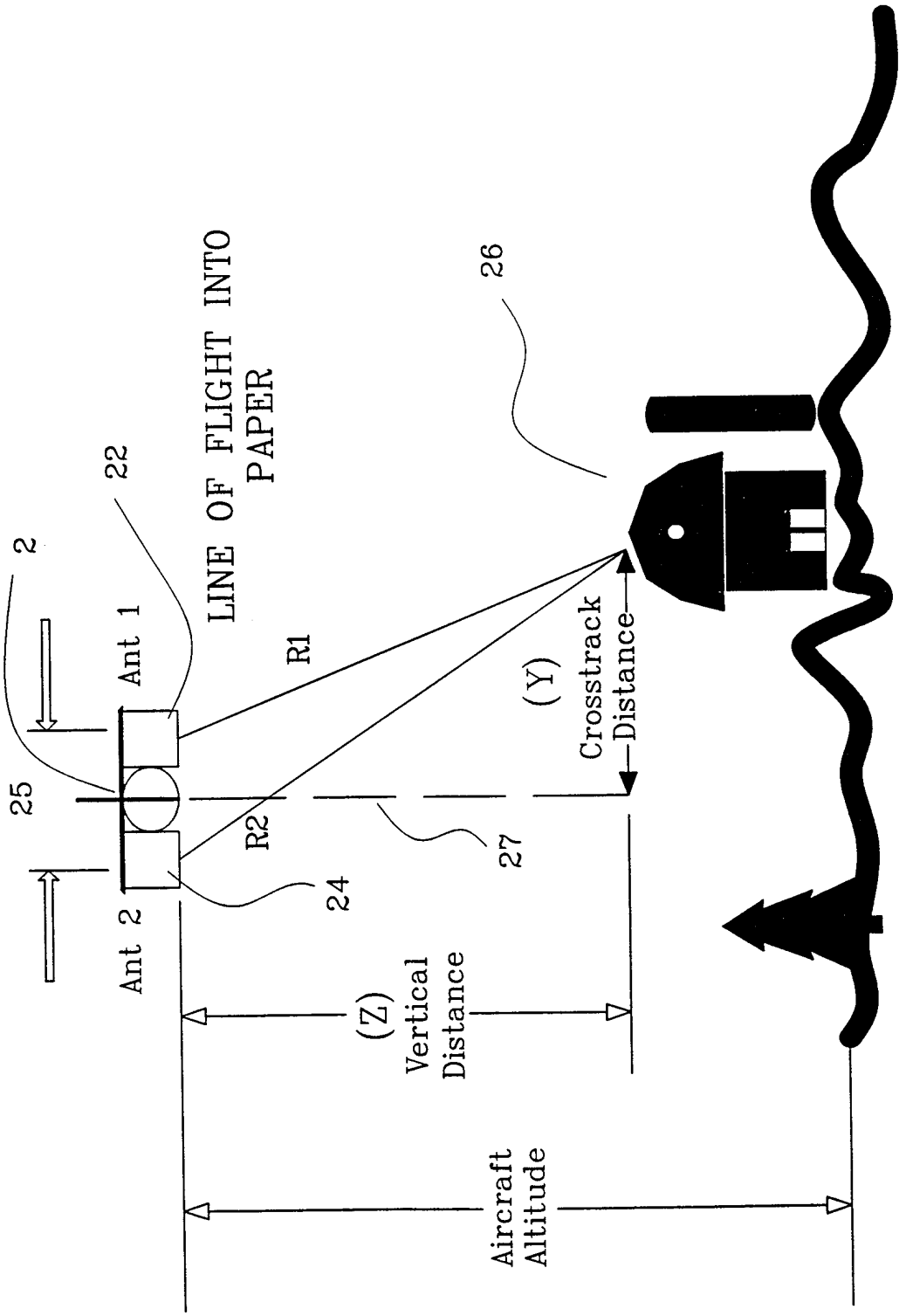

Antenna 1
Course Search of Next Swath 12
Phase Comparison of Present Swath 14
Antenna 2
Fine Search of Present Swath 14
Phase Comparison of Present Swath 14

*Fig.2*


2
22
LINE OF FLIGHT INTO PAPER
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Ant 1
R1
(Y) Crosstrack Distance
25
R2
27
24
Ant 2
(Z) Vertical Distance
Aircraft Altitude

Fig. 3

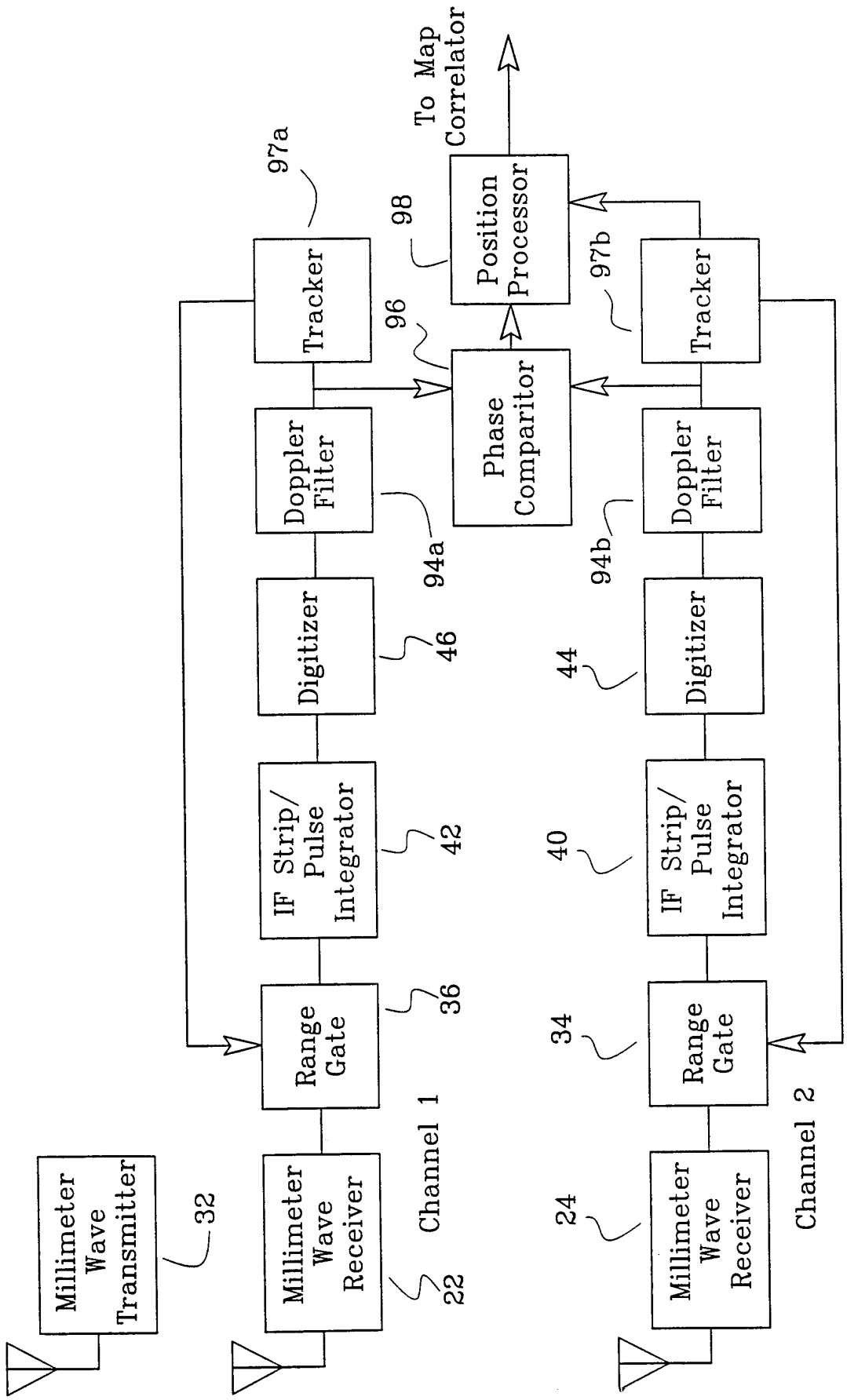
Millimeter Wave Transmitter
32
Millimeter Wave Receiver
22
Channel 1
Range Gate
36
IF Strip/ Pulse Integrator
42
Digitizer
46
Doppler Filter
94a
Tracker
97a
Phase Comparitor
96
Position Processor
98
To Map Correlator
Millimeter Wave Receiver
24
Channel 2
Range Gate
34
IF Strip/ Pulse Integrator
40
Digitizer
44
Doppler Filter
94b
Tracker
97b

*Fig. 4*

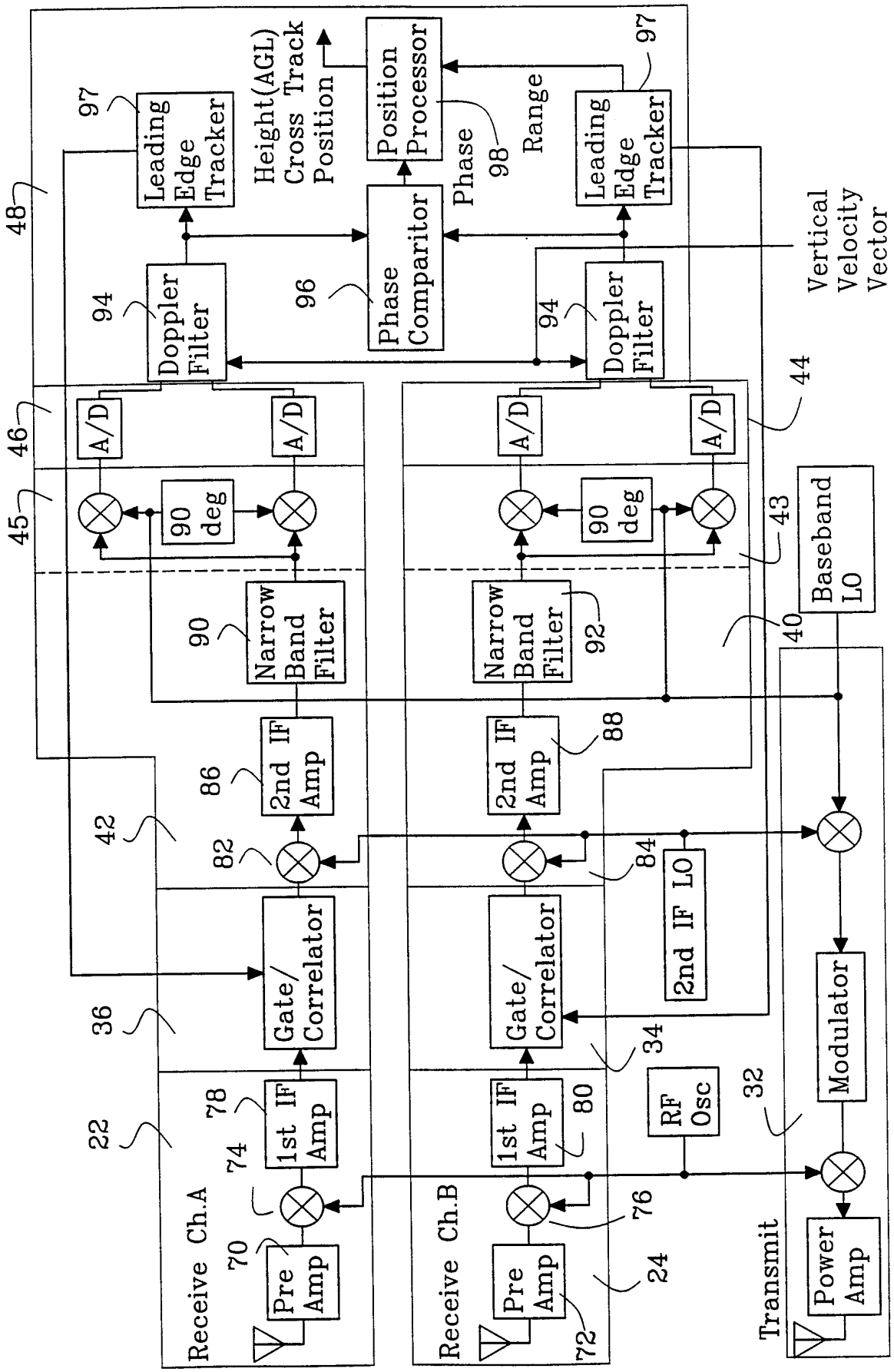
Low Cost Interferometric Synthetic Aperature Radar Altimeter
Receive Ch.A
Receive Ch.B
Transmit
Pre Amp
1st IF Amp
Gate/ Correlator
2nd IF Amp
Narrow Band Filter
90 deg
A/D
Doppler Filter
Leading Edge Tracker
Phase Comparitor
Position Processor
Height(AGL) Cross Track Position
Range
Phase
Vertical Velocity Vector
RF Osc
2nd IF LO
Baseband LO
Modulator
Power Amp
22
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Fig. 5

# INTERNATIONAL SEARCH REPORT

Inter nal Application No
PCT/US 99/13292

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G01S13/90

According to International Patent Classification (IPC) or to both national classification and IPC

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Minimum documentation searched (classification system followed by classification symbols)
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Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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| Y | US 5 608 405 A (PRITT MARK D)<br>4 March 1997 (1997-03-04)<br>column 1, line 9 -column 1, line 31<br>column 4, line 11 -column 4, line 56;<br>claim 1; figures 1-4 | 1-3 |
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[X] Patent family members are listed in annex.

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| Date of the actual completion of the international search | Date of mailing of the international search report |
|---|---|
| 13 October 1999 | 28/10/1999 |

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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

| Category ° | Citation of document, with indication,where appropriate, of the relevant passages | Relevant to claim No. |
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1

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Information on patent family members

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PCT/US 99/13292

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